GREIT: Consensus EIT algorithm for lung images

Lots of authors! Our criteria is "have contributed data, code, testing or in discussions and agree with consensus. *You can join us if you'd like*

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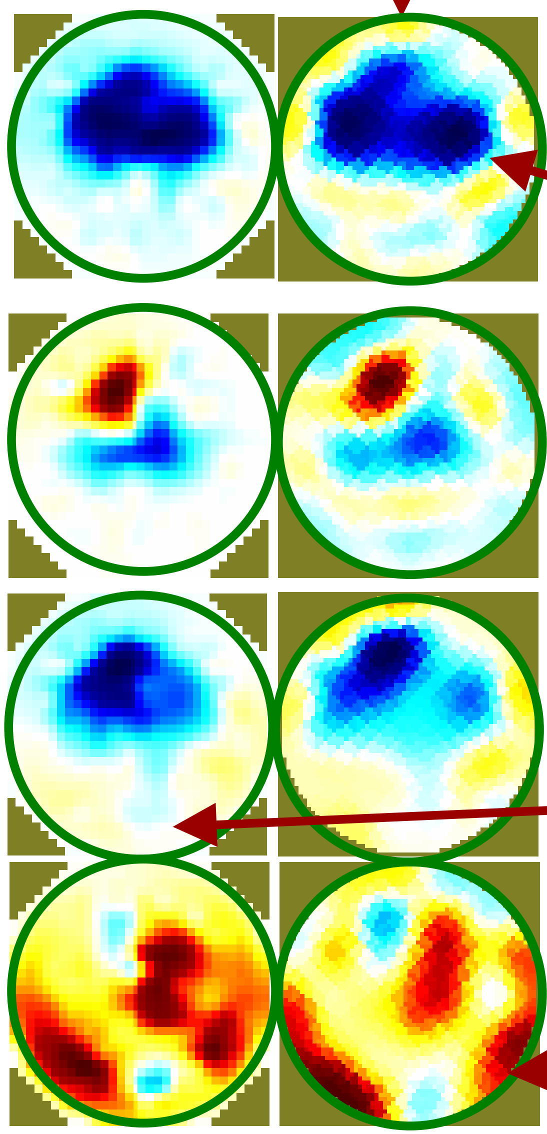
Backprojection vs Gauss-Newton

Healthy pig with volume controlled ventilation
Protocol: PEEP (0cm,5cmH_2O) x F_IO_2 (21%,100%)



VT ZEEP

VT PEEP – ZEEP

EELV PEEP – ZEEP

EELV O2 – air

GN separates lung regions

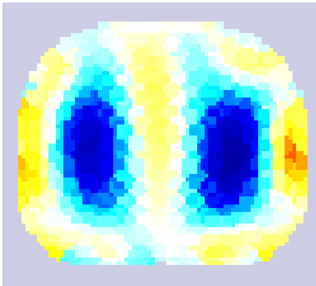
BP shows less boundary artefacts

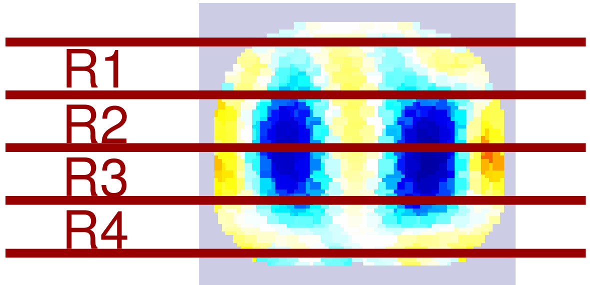
BP pushes boundary effects to centre

Do we need a new algorithm?

Problems with proposed algorithms:

- "Is that image feature physiological or artefact?"
- "Can we compare regions?"
- choice of parameters
- details of the "secret sauce"





GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

stands for:

Graz consensus Reconstruction algorithm for Electrical Impedance Tomography

- Initial work at Graz ICEBI/EIT conf.
- Easy to pronounce

GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

- Aim is to get large representation of math/engineering and physiological communities.
- This will encourage EIT system vendors to provide it as standard
- Allows multi-centre EIT trials

GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

What’s in it for participants?

- There is no financial interest here. We’re not trying to achieve lock-in to benefit commercially

Benefits are:

- Inter-centre comparison
- Helping EIT acceptance
- Name on a paper.

GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

This work is limited to the reconstruction algorithm.

- No image interpretation
- No clinical/physiological tests specified

GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

Linear algorithm for time difference imaging.

- Fast reconstruction allowing real time
- Linear algs are better understood with noisy data
- No absolute reconstruction
- No advanced (e.g. total variation) schemes

GREIT: a consensus linear reconstruction algorithm for EIT images of the chest

Algorithm is focused on lung EIT.

Geometric models for

- Adult thorax
- Neonate thorax
- Cylindrical phantom

Method for variations in

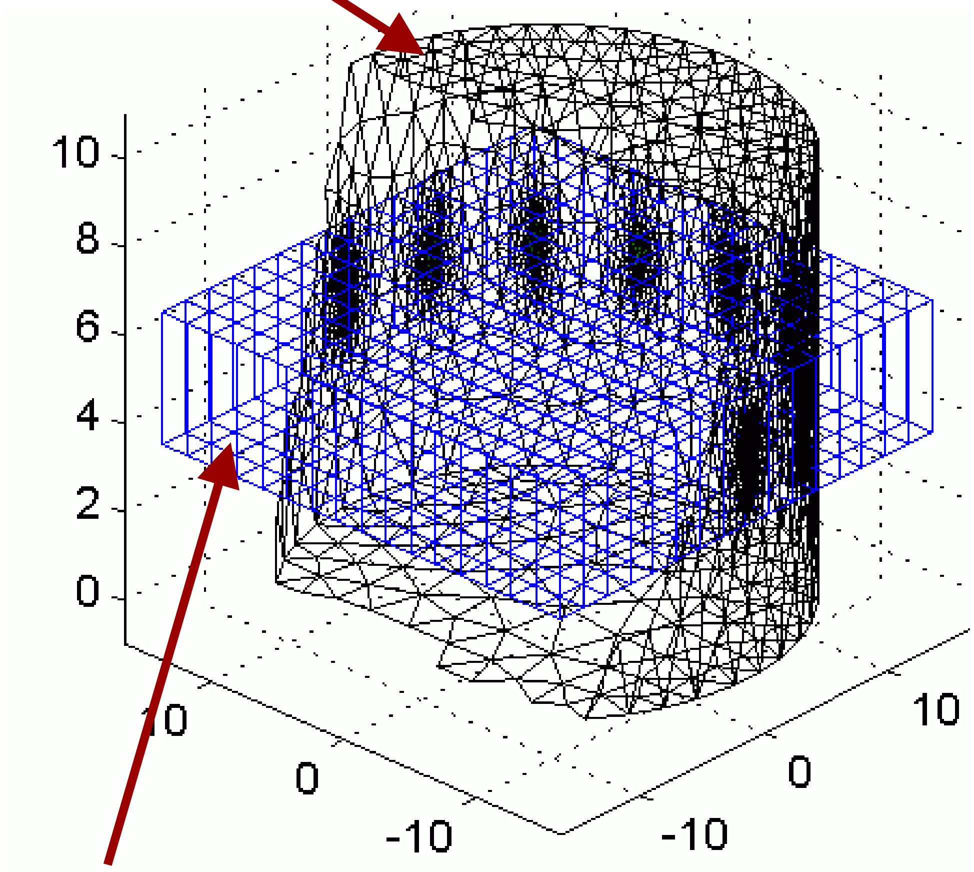
- Animals thoraces
- Electrode sizes
- Patient shapes

Step 1: Ingredients

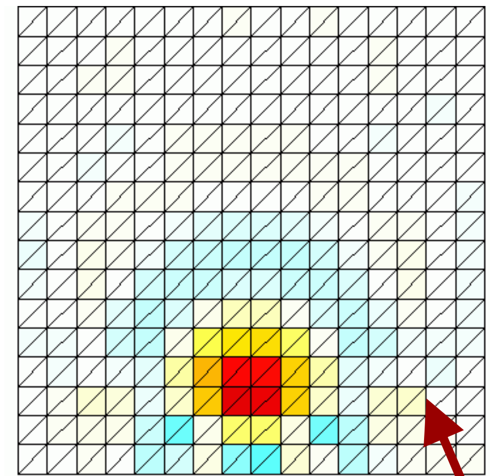
- Dual model (2D coarse / 3D fine)
- Gauss Newton reconstruction
- Image prior with spatial filter
- Scaling for spatial uniformity
- Hyperparameter selection method
- Electrode movement compensation

Agreed: Dual Models

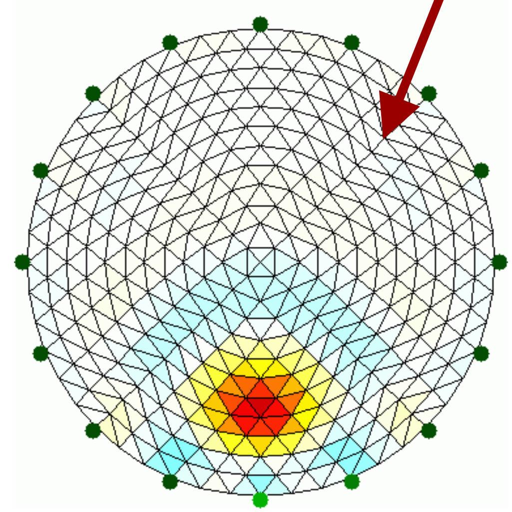
Fine Mesh: fwd_model
(with complete electrode model)



Square mesh: rec_model



We reconstruct to square pixels, not FEM elems



Agreed: Gauss Newton Reconstruction

$$\hat{\mathbf{x}} = \left((\mathbf{J}^t \boldsymbol{\Sigma}_n^{-1} \mathbf{J} + \lambda^2 \boldsymbol{\Sigma}_x^{-1})^{-1} \mathbf{J}^t \boldsymbol{\Sigma}_n^{-1} \right) \mathbf{y}$$

Tikhonov form

$$\hat{\mathbf{x}} = \left(\boldsymbol{\Sigma}_x \mathbf{J}^t (\mathbf{J} \boldsymbol{\Sigma}_x \mathbf{J}^t + \lambda^2 \boldsymbol{\Sigma}_n)^{-1} \right) \mathbf{y}$$

Wiener filter form

Post scaling for units & spatial uniformity

Also test normalized difference

Quantity	symbol
Difference Measurements:	$\mathbf{y} = \mathbf{v}^1 - \mathbf{v}^2$
Conductivity image:	$\hat{\mathbf{x}}$
Image prior covariance:	$\boldsymbol{\Sigma}_x$
Measurement covariance:	$\boldsymbol{\Sigma}_y$
Jacobian:	$\mathbf{J}$
hyperparameter:	λ

Agreed: Image Prior with spatial filter

- Spatial filter priors are more flexible

Spatial filter type prior

1	-½				
-½	1	-½			
	-½	1	-½		
		-½	1	-½	
			-½	1	-½
				-½	1

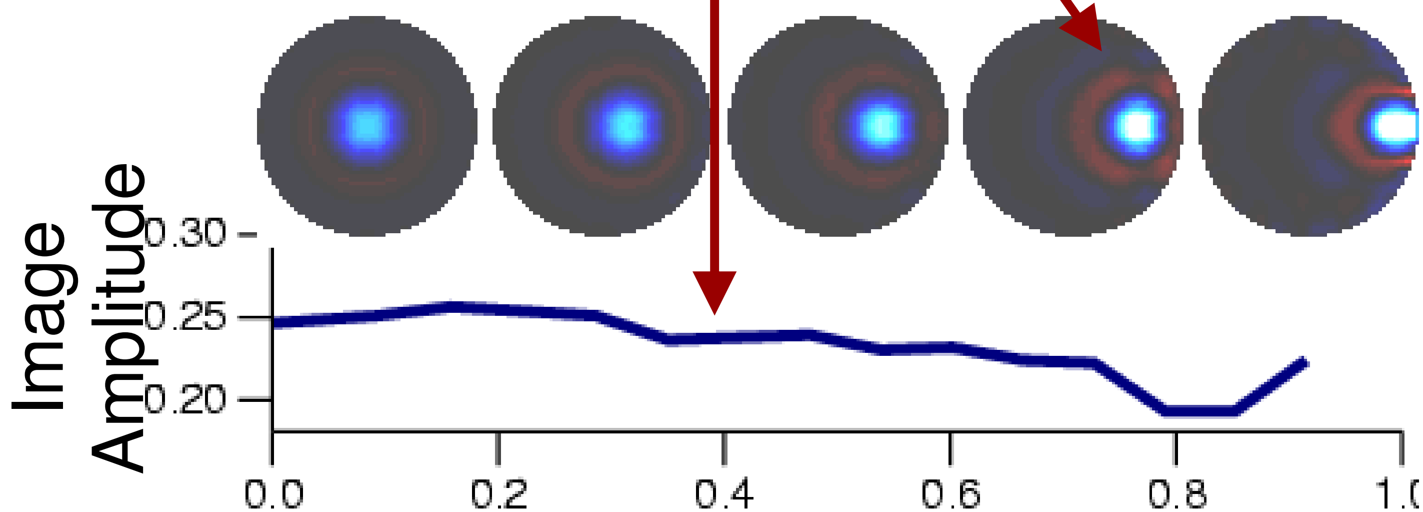
Diagonal type prior

1					
	1				
		1			
			1		
				1	
					1

To Do: Choose prior

Image prior: requirements

- Reduce ringing/overshoot
- Reduce position error
- Uniform amplitude response
- Uniform resolution + shape



Hyperparameter λ selection

- We can’t have user selectable λ
- We can’t have λ depend on each image

To Do: select scheme to choose λ.

Possibilities:

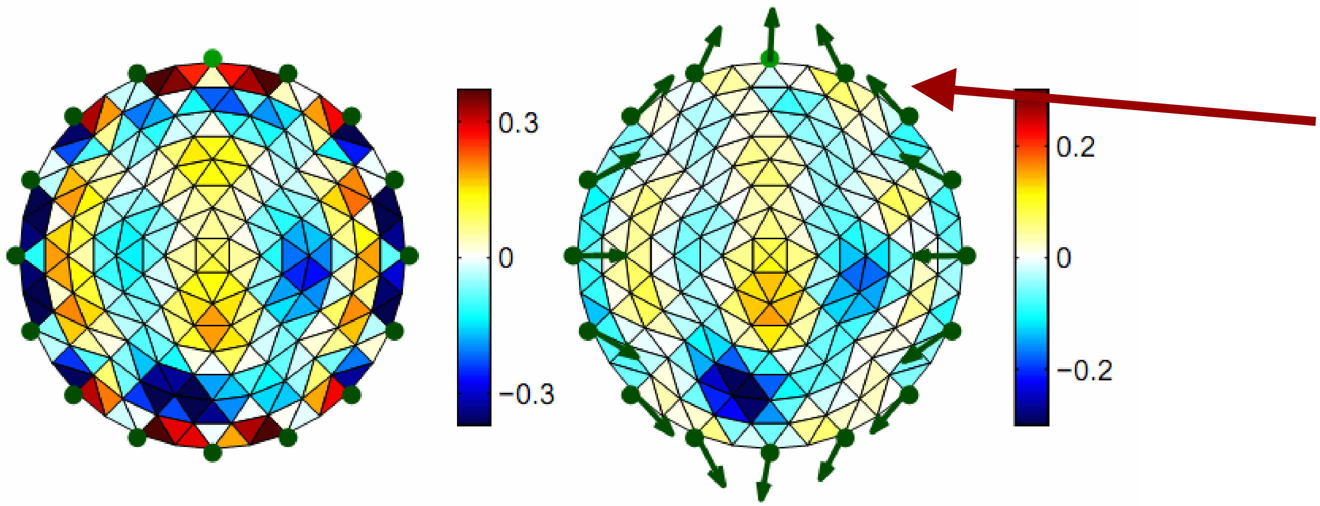
- manufacturer calibration
- calibration test procedure (including defined phantom)

Electrode movement artefacts

From Soleimani et al (2006)

$$\hat{\mathbf{x}} = \left(\mathbf{J}^t \frac{1}{\sigma_n^2} \mathbf{W} \mathbf{J} + \frac{1}{\sigma_c^2} \mathbf{R}_c + \frac{1}{\sigma_m^2} \mathbf{R}_m \right)^{-1} \mathbf{J}^t \frac{1}{\sigma_n^2} \mathbf{W} \mathbf{z}.$$

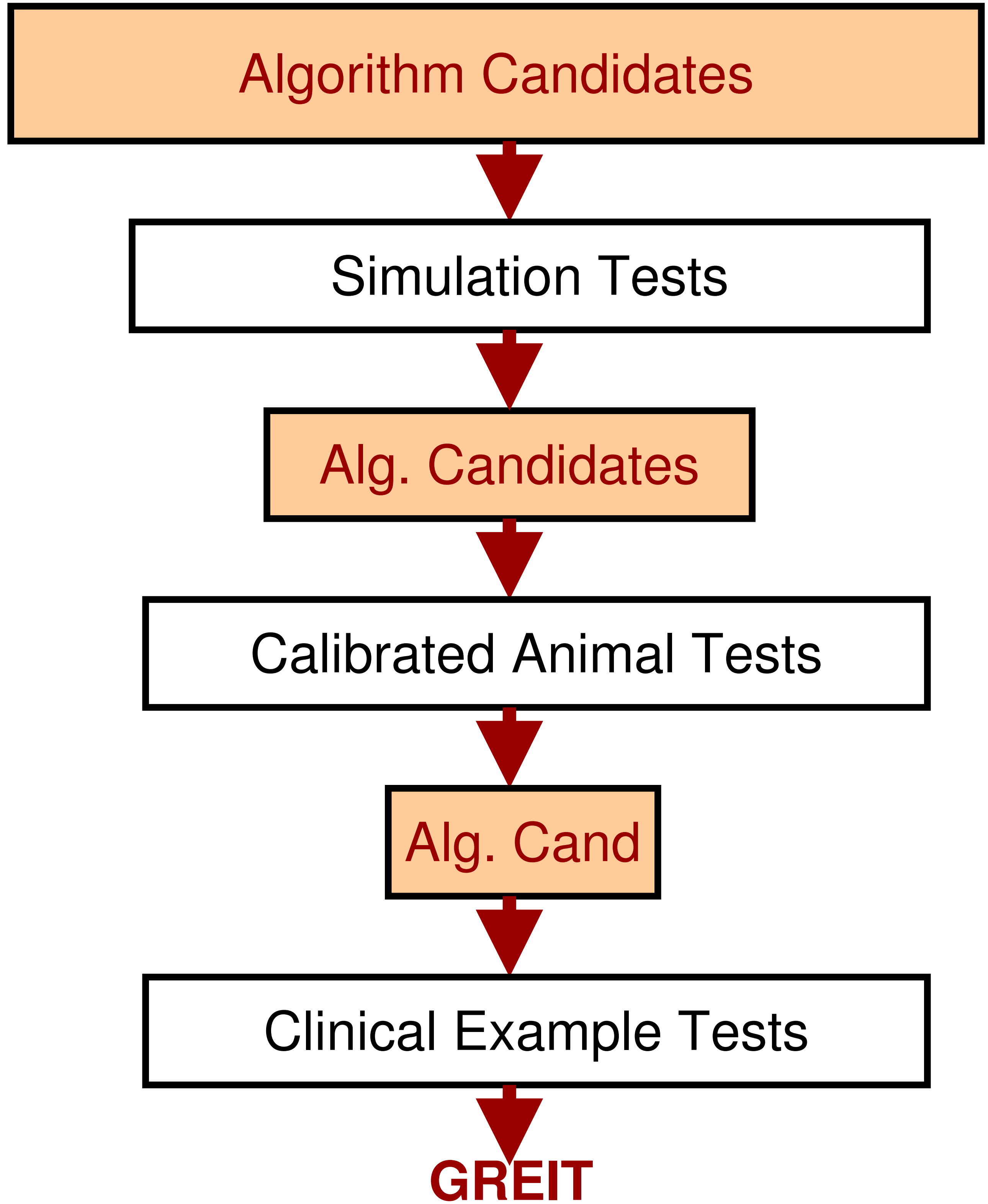
define $\mathbf{R} = \mathbf{R}_c + \mu^2 \mathbf{R}_m$, and rewrite (6) as (using $\mathbf{W} = \mathbf{I}$),



Arrows aren't accurate (conformal problem), but artefacts are reduced

Figure 2. Reconstructed images (256 element mesh) for phantom data with two non-conductive objects: one on the positive x-axis, the other on the negative y-axis. Arrows indicate each electrode's movement, and are scaled by 10×. *Left*: Reconstructed image with standard method using $\lambda = 10^{-2}$ (AAM = 0.134). *Right*: Reconstructed image including electrode movement using $\lambda = 10^{-2}$ and $\mu = 10$ (AAM = 0.0273).

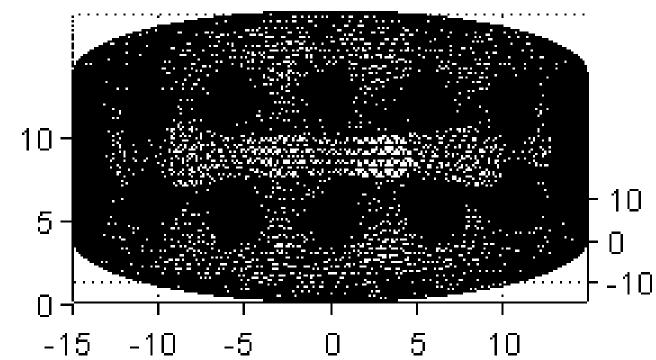
Evaluation

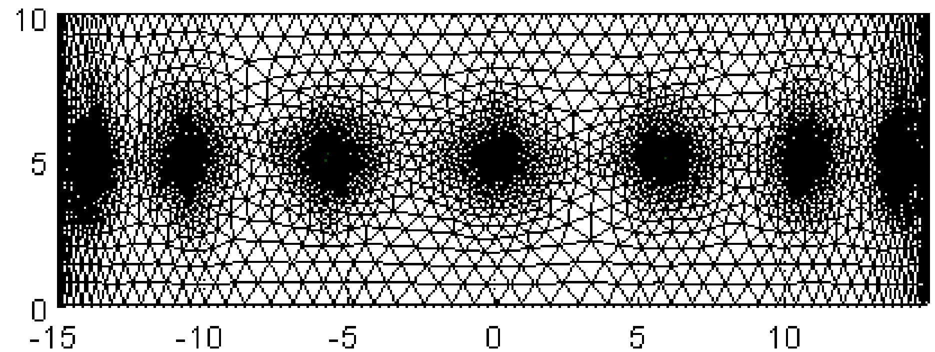

Algorithm Candidates
Simulation Tests
Alg. Candidates
Calibrated Animal Tests
Alg. Cand
Clinical Example Tests
GREIT

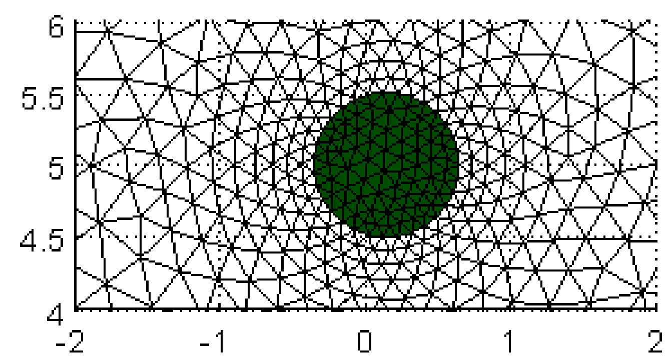
Simulation Tests

1. Numerical models
2. Tests

- Amplitude response
- Position error
- Resolution
- Noise performance
- Boundary shape and electrode sensitivity

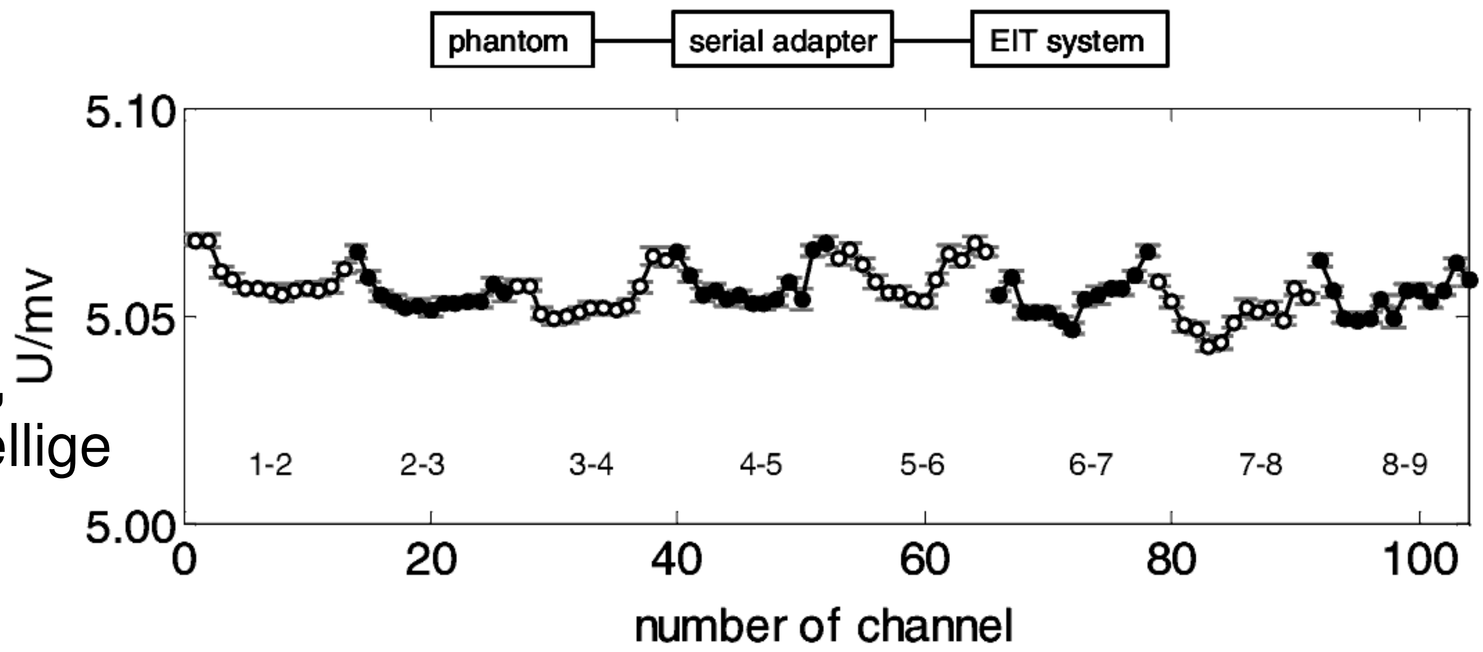






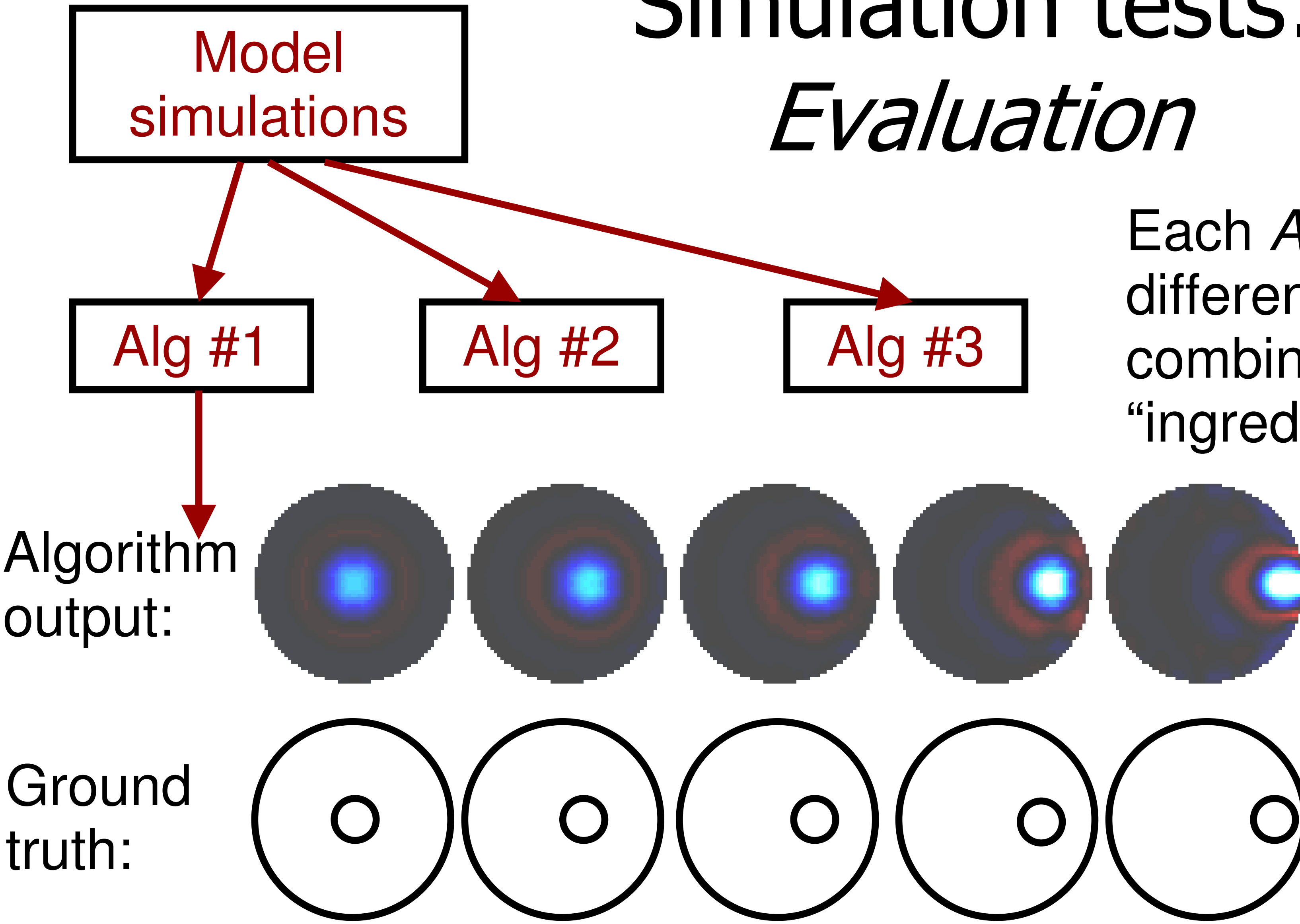
Simulation test noise

- EIT noise is not white and Gaussian, but is driven by electronics
- Use phantom noise measures from Göttingen and Montréal



Hahn, Just, Dittmar, Hellige (2008)

Simulation tests: *Evaluation*

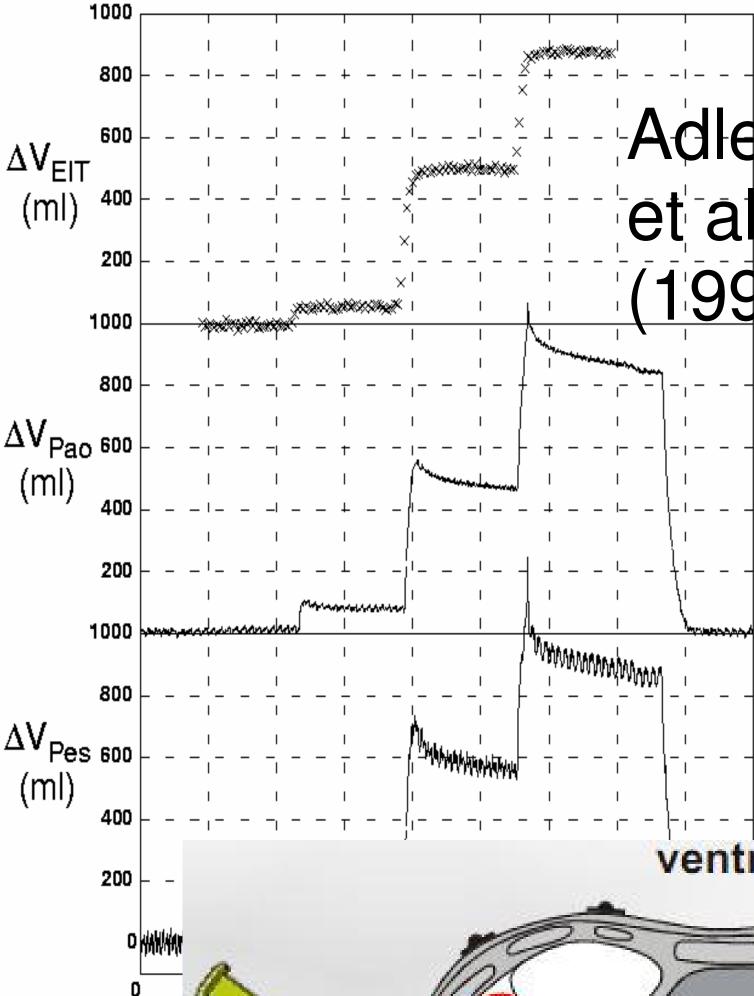


Each *Alg* is a different combination of "ingredients"

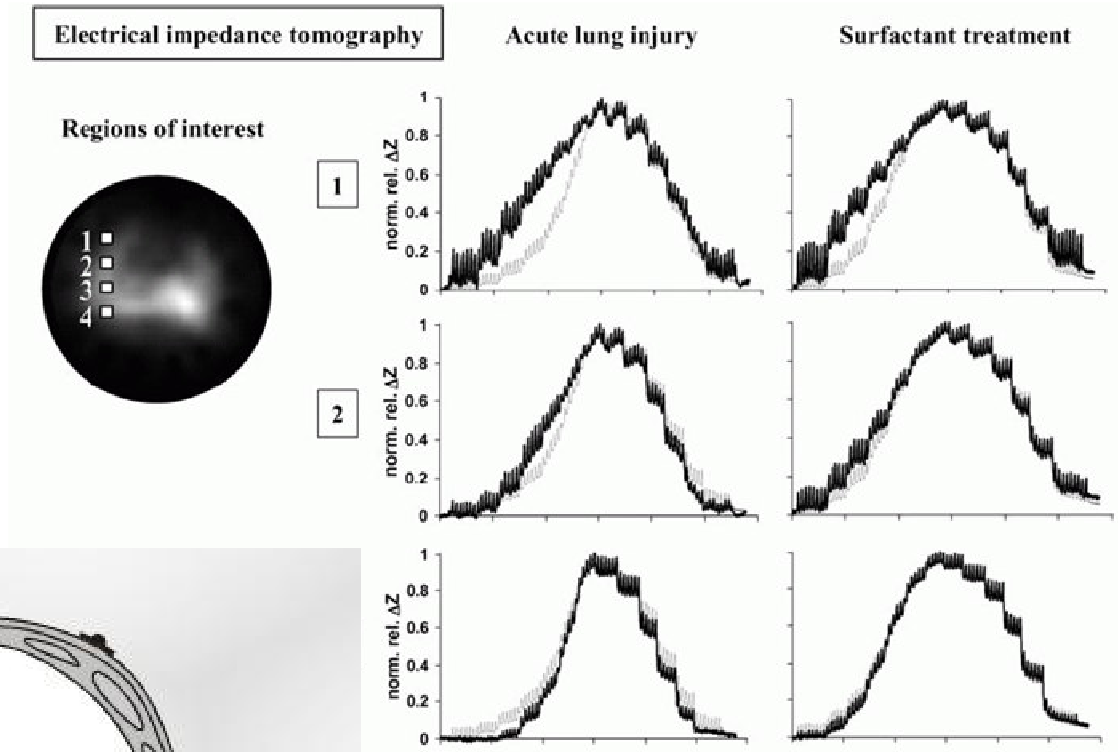
Calibrated Animal Tests

	Data Description	*Ref*	*EIT system*
1	Experimental lung injury (pigs) oleic acid via P.A.	Frerichs *et al*, 1998	Sheffield MK I
2	Air/fluid in pleural space (pigs)	Hahn *et al*, 2006	Goe MF II
3	Fluid instillation in lung (dogs)	Adler *et al*, 1997	Montreal, 1990
4	"Supersyringe" lung volumes (dogs)	Adler *et al*, 1998	Montreal, 1993
5	PEEP trial in untreated/treated acute lung injury (pigs)	Frerichs *et al*, 2003	Goe MF II

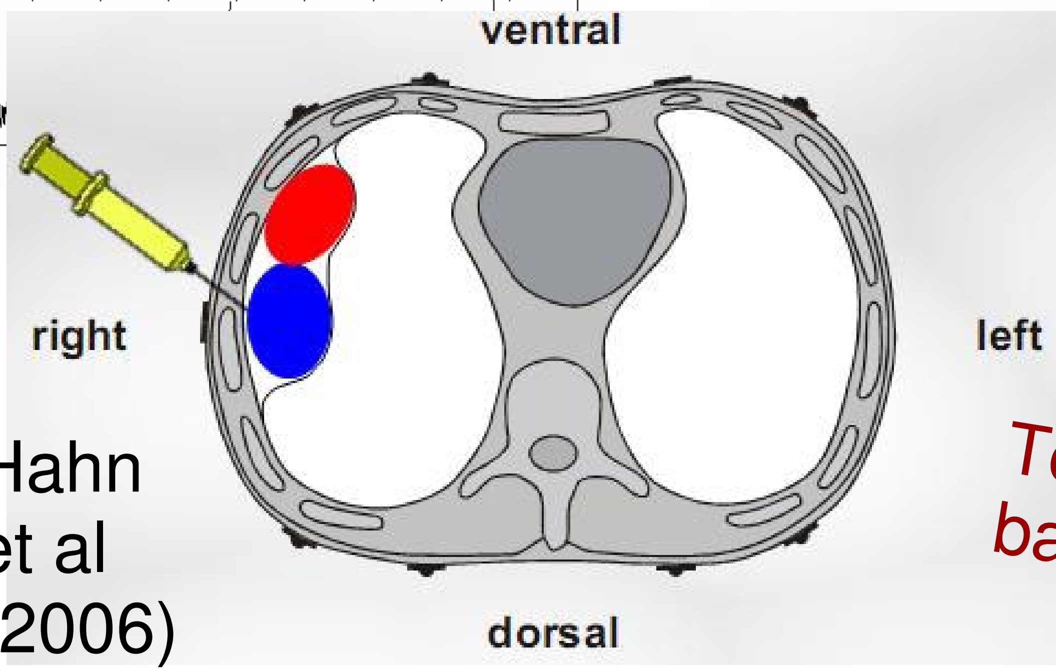
Calibrated animal tests



Adler et al (1996)



Frerichs et al (2003)

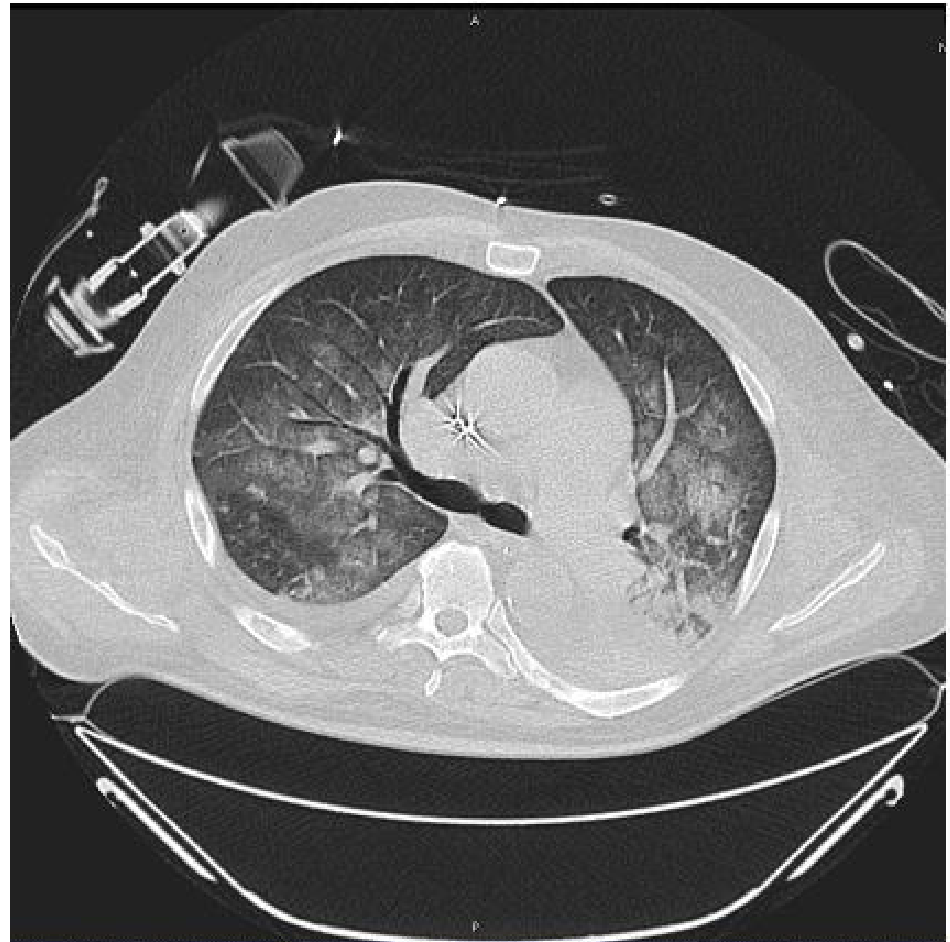


Hahn et al (2006)

To Do: Design tests based on these data

Clinical case

- **Patient data** male 59 yrs 188 cm 120 kg
- **Current diagnosis** Sepsis with acute lung injury Acute renal failure (continuous dialysis) Atelectasis left lower lung lobe
- **Medical history** Implantation of cardiac pacemaker Arterial hypertension
- EIT measurements performed in the ICU
- **Mode** Continuous positive airway pressure ventilation with assisted spontaneous breathing (CPAP/ASB)
- $\mathbf{F_IO_2}$ 0.5 **PEEP** 9 cmH2O **Frequency** 25 breaths/min **Minute ventilation** 15.1 l/min
- During the EIT measurement of 180 s duration approx. after 60 s PEEP was reduced from 9 to 5 cmH2O and after 120 s increased to 13 cmH2O.
- $\mathbf{P_{peak}}$ 20 cmH_2O $\mathbf{P_{mean}}$ 13 cmH_2O at **PEEP** 9 cmH_2O $\mathbf{SO_2}$ 97 %
- $\mathbf{P_{peak}}$ 16 cmH_2O $\mathbf{P_{mean}}$ 9 cmH_2O at **PEEP** 5 cmH_2O $\mathbf{SO_2}$ 92 %
- $\mathbf{P_{peak}}$ 24 cmH_2O $\mathbf{P_{mean}}$ 16 cmH_2O at **PEEP**13 cmH_2O $\mathbf{SO_2}$ 97 %



To Do: Design tests based on these and other clinical data

“Roadmap”

Step 1: Agree on “ingredients” and “roadmap”

- This paper/presentation

Step 2: Develop software and evaluation

- Test algorithm and discuss (June -Sept)

Step 3: Consensus where possible

- publish paper and software (Oct-Nov)